
Geological and structural interpretation of possible mineralization zones of part of Anambra basin and Southern Benue Trough using airborne geophysical data.

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Abstract

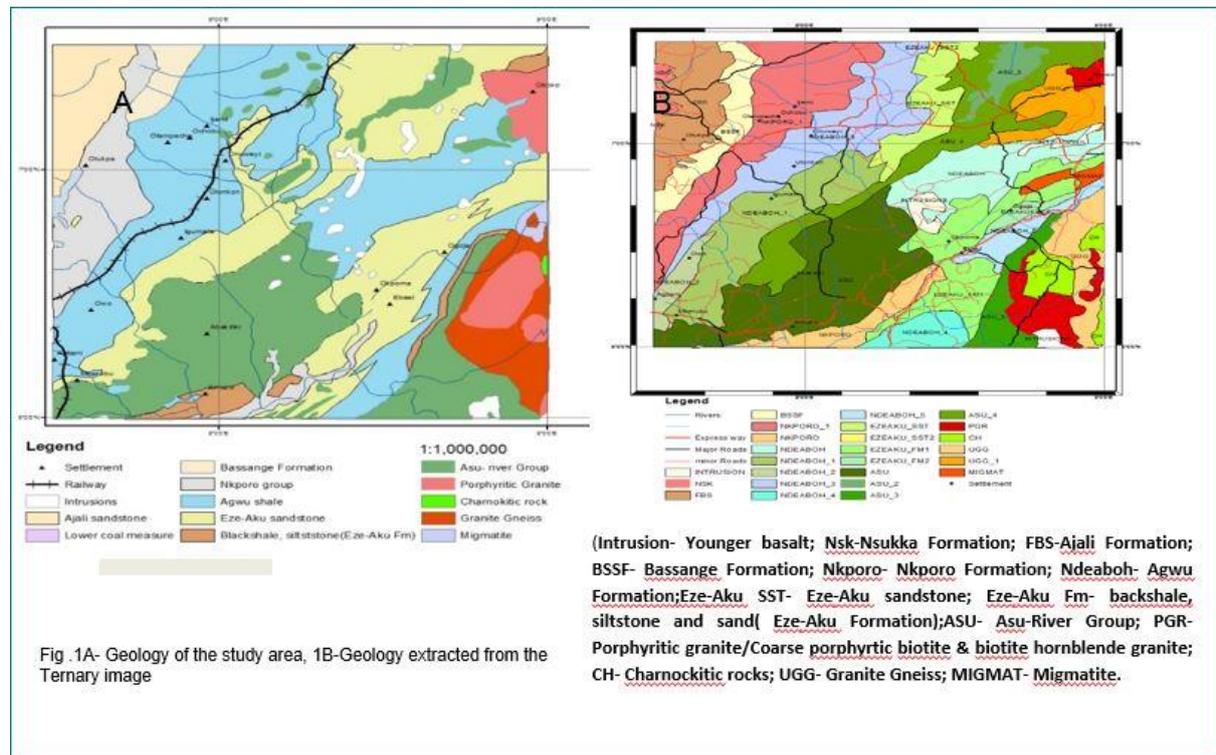
Nine (9) high-resolution of aeromagnetic and radiometric data of the Benue Trough and adjacent Anambra Basin, were evaluated to understand the subsurface geological structure of the area. Various data enhancement/derivative techniques like analytic signal, first and second vertical derivatives, horizontal derivative and tilt derivative were employed in delineating magnetic lineaments, edges, lithological boundaries, and contact zones within the area. The results obtained revealed magnetic lineaments, shear zones and shallow faults, trending mostly in NE-SW, E-W, and NW-SE directions. The ternary image generated from Radiometric data using oasis Montaj software highlights the lithology of Asu River Group, Eze-Aku Formation, Agwu Shale, Nkporo Shale, Nsukka Formation and Ajali Sandstone. This shows an improved version of the geological mapping of the study area

Keywords: Lineaments, Structures, Filtering, Magnetic field.

INTRODUCTION

Magnetic data gives information on the structural fabric of the basement but improvements in instrument resolution and acquisition techniques have allowed for the utilization for mapping weakly magnetic intra-sedimentary structures. High resolution airborne magnetic and gamma ray spectrometric surveys are fundamental to modern geoscientific mapping. They provide cost-effective definition of structure lithology (Telford et.al, 1990). Airborne radiometric survey is used to measure variations in the radioactive minerals composition in order to map lateral lithological changes (Wilford et.al, 1997). This method involves the measurement of naturally occurring radioactive elements that exist in rock forming minerals and soil profiles. These lateral variations

produce anomalous regions which are indicative of radioactive of structural or lithological contrasts. The geographical information system (GIS) has facilitated an unprecedented integration of digital geophysical data with independent vector and raster information. A GIS allows the ready amalgamation of diverse data sets such as remotely sensed images, digital elevation models, magnetic data, electromagnetic data, gamma ray data and gravity data, to name but a few.



Geology of Southern Benue Trough and Upper Anambra Basin:

The study area covers the Southern Benue trough, upper Anambra basin and Nigeria Basement complex bounded it at the South Eastern portion of the study area. The area is bounded by Longitude 7.30°E to 9.00°E and Latitude 6.00°N to 7.30°N. During the Cretaceous, progressive sea level rise from Albian-Maastrichtian are the main factor responsible for sedimentation within the Benue trough.

Albian-cenomanian: Asu River Group represents the first and oldest unit of shallow marine to brackish water sediments deposited on the basement complex. The group occupies the core of the Abakaliki fold belt (Nwajide, 2013). The subdivision of the group into the component formations by Reymont (1965) has been in use. But Nwajide (2013) has repackaged Asu River Group such that the Ogoja Sandstone, Awi Formation, Mamfe Formation, Abakaliki Formation and Mfamosing limestone are all under Asu River Group Formations. Ogoja sandstone is the basal parts of the Asu River group and consists of conglomerates and arkosic sandstones in both Ikom and Ogoja areas (Uzuakpunwa, 1980; Petters et.al 1987). The Awi Formation is the basal, non-calcareous, sandy, conglomeratic unit of the Asu River Group directly overlying the Basement complex (Oban Massif) north of Calabar. The sediment is Albian sediment which always deposited in a shallow marine environment (Reymont; 1965).

Turonian-coniacian: These are the “Eze-Aku shale Group” (Murat, 1972). It includes all the stratigraphic units deposited in the Late Cenomanian to Turonian in the Lower Benue Trough (Nwajide, 2013). Eze-Aku Formation overlies the Asu River Group and it consists of black calcareous shales, shelly limestone, siltstone and sandstone, which were deposited as a result of renewed transgression in the second depositional cycle of the Benue Trough (Kogbe, 1976). The age has been suggested to be late Turonian through Coniacian to Early Santonian and this is because of the kind of fossil assemblage – mainly Planktic foraminifera assemblage.

Campanian-Maastrichtian: This marks the beginning of deposition within the Anambra Basin and the third cycle of marine incursion in the Benue Trough. Nkporo Shale and their lateral/statigraphic units of the Anambra basin overlies an angular unconformity. Outcrop of Nkporo shale are scarce, but cored boreholes show that the Formation consists of dark shale and mudstone with occasional thin beds of sandy shale and sandstone (Reyment, 1965). Ogugu Shale is deposited conformably on the Agbani Sandstone. It is generally medium to coarse grained and contains pebble bands, occasionally thin silty, or argillaceous, layers are present. Mamu Formation (Lower coal measures) overlies the Nkporo shale. This consists of fine grained sand, carbonaceous shales and coal with the thickest seam of 1 km typifying a transitional environment. Its type locality is the Enugu Cuesta. The Ajali Sandstone (Middle coal measures) overlies the Mamu Formation conformably.. The Nsukka Formation (Upper coal measures) is the youngest formation from this cycle consisting of interdigitations of very fine-grained sandstones, dark shale and coal indicating a paralic environment of Maastrichtian to Paleocene age.

Paleocene sequences: These are deposited as a result of the Paleocene transgression and Eocene regression, which led to the deposition of Imo Shale and Ameki Formation respectively, grading to the proximal Niger Delta. (Agagu, et.al 1982). Imo Shales consists of clayey shale, with clay ironstones and sandstone bands. It rests conformably on the Nsukka Formation and forms a down dip continuation of the Akata Shales in the Niger Delta (Reyment, 1965). Ameki Formation overlies the Imo shales and consists of highly fossiliferous greyish–green, sandy clay with calcareous concretions and white clayey sandstones. It displays a rapid lateral facies change, with local shale development or inclusions of sandstones; carbonaceous plant remains may be present. The geology of study area is shown in fig. 1a.

MATERIAL AND METHODS

DATA SOURCE: A massive country-wide airborne geophysical survey was commissioned in the year 2006 by the government of the Federal Republic of Nigeria and was awarded to Fugro Airborne surveys of South Africa. While the processing and initial interpretation was contracted to Paterson, Grant and Watson Limited (PGW).The magnetic survey was done together with radiometric survey and it was flown at 500m Tie-line spacing and 80m terrain clearance; with a flight line spacing of 500m at 135 degrees azimuth flight line trend. This gave a highly resolution data adequate for this research. The magnetometer used was Caesium vapour SCINTREX CS2 and the survey was flown along NW-SE direction (i.e. perpendicular to the axis of the basin). The nine(9) sheets aeromagnetic data procured from the Nigerian Geological Survey Agency. 31, Shetima Mangono Crescent Utako District P.M.B 616, Abuja., are sheet 269, 270, 271, 288, 289, 290, 302, 303 and 304. The aeromagnetic data were obtained alongside the radiometric data were The software used in this study include: Ilwis 3.0 (academic), Arc GIS 9.3, and Oasis Montaj 6.4.2,

Excel spreadsheet.

Airborne geophysical data processing and interpretation were carried out using Oasis Montaj 6.4 mapping and processing system with geosoft executable (GX) plugins. This involved generation of information related to structural features in the frequency and space domain using automated Fast Fourier Transforms (FFT).

Vertical derivatives: It filters amplify the high frequency components of the data (Erwin et.al 1995). It accentuates gradients along edges of shallow magnetic structures. Hence, it is sometimes used to locate edges of magnetic bodies and to emphasize source at shallow depth (Dobrin and Savit, 1988).

The equation of the wavenumber domain filter to produce nth derivative is

$$F(\omega) = \omega^n$$

Where

$F(\omega)$ = amplitude at wave number, ω in radians/unit ($\omega = 2\pi k$; k is in cycles/unit) and n is the order of differentiation.

Analytical signal: The idea is to present magnetic anomaly information stripped of dependence on the inclination of the earth inducing field so that anomalies are positive and sit directly above their sources (Roest et.al, 1992). The analytical signal was calculated to extract the location of magnetic sources contacts or edge. The analytical signal showed discontinuities, some of which coincide with the geological boundaries at the area. This function and its derivatives are independent of strike, dip, magnetic declination, inclination and remnant magnetization (Nabighian 1972, 1974, 1984; Roest et.al. 1992) is a function related to magnetic fields by the derivatives: Analytical signal uses the square of the analytical signal amplitude defined as:

$$\text{The 3D analytical signal } A \text{ of a potential field anomaly } |A(x, y)|^2 = \left(\frac{\delta M}{\delta x}\right)^2 + \left(\frac{\delta M}{\delta y}\right)^2 + \left(\frac{\delta M}{\delta z}\right)^2$$

Where M =magnetic field,

HORIZONTAL GRADIENT: A horizontal gradient was proposed by Butler (1984). The horizontal derivative produced an “edge” map where the high data values are centred over the edges of the magnetic sources (e.g to highlight faulting relationships). Use of the horizontal gradient for locating the edges of magnetic sources developed as an extension of Cordell’s (1979) technique to locate edges of tabular bodies from the steepest gradients of gravity data (Nabighian, et.al., 2005). The total horizontal derivative enhancement is designed to look at fault and contact features. Maxima in the mapped enhancement indicate source edges. It produces a more exact location for faults and tends to locate buried masses than first vertical derivative. The horizontal derivative (THDR) computes the maxima over the edges of the structures.

$$THDR = \sqrt{\left(\frac{\partial T}{\partial X}\right)^2 + \left(\frac{\partial T}{\partial Y}\right)^2}$$

Tilt derivative: The tilt derivative utilizes the ratio of the vertical derivative to the absolute value of the horizontal derivative and this overcomes the problem of the shallow and deep sources (Mita, 2009). θ the tilt angle or tilt derivative (Verduzco et. al, 2004) is defined as

$$\theta = \tan^{-1} \frac{\partial f / \partial z}{\partial f / \partial h}$$

Where the total horizontal derivative is

$$\frac{\partial f}{\partial h} = \left[\left(\frac{\partial f}{\partial x} \right)^2 + \left(\frac{\partial f}{\partial y} \right)^2 \right]^{1/2}$$

Since the tilt filter is expressions of horizontal and vertical gradients, it has the tendency to amplify field variations from shallow sources, highlight the location of sub vertical edges and provide estimates of the depth to sources (fig. 13c).

The data was georeferenced using the geographical coordinate system. Image enhancement and analysis were carried out using oasis montaj 6.4 software and the Arcmap™ 10.3 was used to abstract the lineament and the rose diagram was drawn using the ILEWIS 3.1 academic software. The data was analysed qualitatively guided by the geologic concepts of the Anambra and Lower Benue trough.

RESULTS AND DISCUSSION

Total Magnetic Intensity: Due to the dipolar nature of magnetization, the anomalies at the area have both attractive and repulsive components. The total field intensity map shows magnetic field amplitude which reaches 113.12nT (Fig. 2a). The map shows variation in magnetic intensity, indicating variation in either lithology or basement topography. This gave rise to most of the anomalies on the study area. The TMI map comprises both the magnitude of the earth's field plus the anomalous field. Hence, the response of the buried bodies measured in total-field magnetic survey depends on the local direction of the earth's field (Dobrin and Savit, 1998). The anomalies on the TMI map that signifies the basement are characterized by smooth contours and low magnetic relief while the surrounding platform area shows steep gradients and high relief in the TMI magnetic contours (Fig. 5c). The lithology of the basement controls the magnetic relief observed over the sedimentary basin like the study area. The shear zones were also delineated using the contoured total magnetic intensity (Fig. 2A).

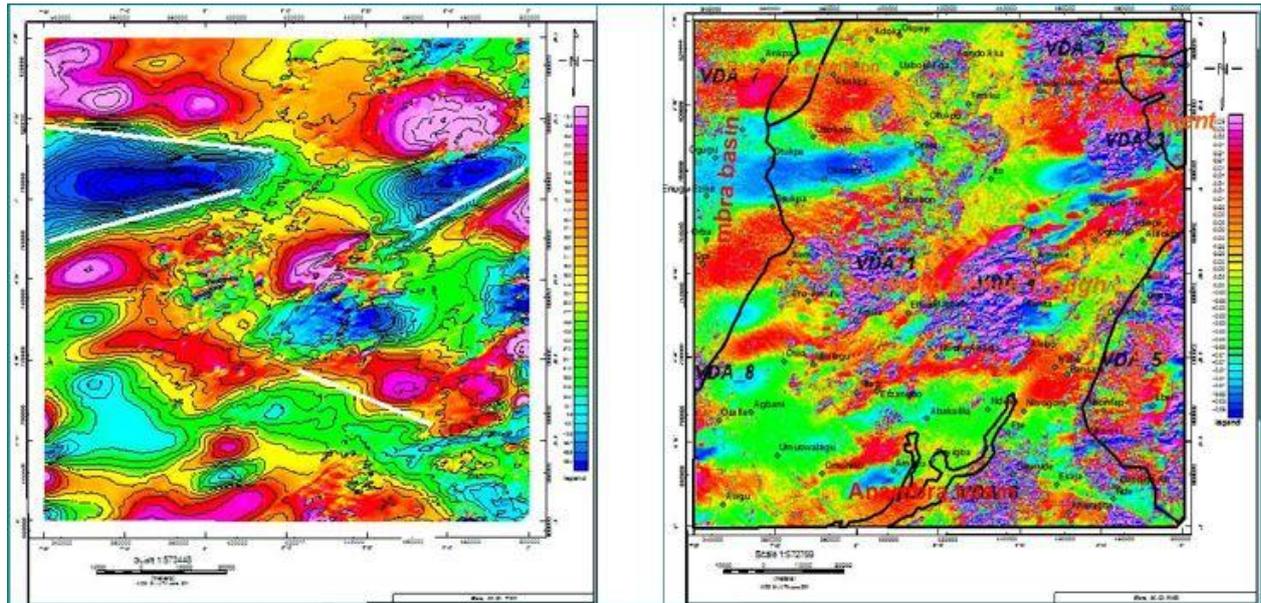
Vertical Derivative processing was undergone to remove long wavelength structures of the magnetic field and significantly improve the resolution of closely spaced and superimposed structures (Keating, P.B, 1995). The shallow and near surface structures are mainly at the northeastern, central and South eastern parts of the study area. Shallow and near surface structures have been identified from the IVD of the TMI map as VDA- 1, VDA- 2, VDA-3, VDA- 4, VDA-5, VDA-6, VDA-7, and VDA-8 respectively (Fig. 2b). Very conspicuous lineaments have been identified at the central portion of the area around Igumale, and northwest of Benta (block VDA - 1 and block- VDA-4). This area is within the Albian Asu River group of Southern Benue Trough. Beds of the Asu-River group facies experienced two deformation (folding) phases (Nwachukwu, 1972a; Amajor, 1985). This area has been known to have been experienced magmatic activity which intruded dolerite and granitic dykes intrusions. This gave rise to hydrothermal ore mineralization like Lead-Zn mineralization. At the north western area of the study area, area covered by Anambra basin sediments, the weakly magnetized source bodies named VDA-7 and VDA-8, represent the ferruginized materials and ironstone capping within the Anambra Basin. At the extremely South Western area of the study area, the basement rocks crop out and give rise to

high frequency magnetic signatures(VDA-5). This area is within Basara, Nkarasi in Ogoja LGA of Cross River state. At Igbor, Aliade and Gboko areas, highly magnetic shallow magnetic sources - VDA_2 which is within the Eze-Aku sandstone formation and VDA_3 on the the Agwu Ndeaboh formation were identified. The rocks at that area are mainly intrusive igneous rocks. Structural trends of the study area was mapped by extracting the lineaments using first vertical derivative of the study area (see fig. 4a) In some cases lineaments reflects the strike lines of elongated intrusive features or surface of large faults reflected in the basement topography or lithology (Dobrin and Savit, 1988). Such features are often concealed under sedimentary cover and show only on magnetic maps. Lineaments create conduits which aid the flow of fluids. These lineaments are assumed to be the surface effects of fracture zones of tensional or shear type (Nwajide, 2013). From the Rose diagram plotted using the azimuthal angle of lineaments; they are trending mainly in NE-SW, E-W, N-S with the NE-SW trend being dominant (Fig 4b). The delineated geological and structural map from the magnetic data is shown in Fig. 5b.

TILT DERIVATIVE: Tilt angle derivative filter is an expression of horizontal and vertical gradients. It is related to the analytical signal in their tendency to amplify field variations from shallow sources, highlighting the location of sub vertical edges and provide estimates of depth to sources according to their sharpness of the (when RTP) Tilt derivative reveals the angle different between the magnetic field. It was used to enhance the contact and boundaries between magnetic sources (Fig 2d).

ANALYTICAL SIGNAL: Analytical signal filter is used here as a reduction to the pole because of the location of the study area (close to the equator). The analytical signal amplitude maximizes over the edges of the magnetic structures and was used to delineate the edges and contact of lithological units regardless of the direction of magnetization (Macleod et.al, 1993). The amplitude analytical signal is used to block out eight source bodies named ASA_1 to ASA_8 and to demarcate the area into domains; amplitude domain of regions having outcrops with high amplitude values that range from 0.061 to 4.328cycles (shown in pink colour). Regions with medium amplitudes range from 0.015 to 0.036 cycles. This is region with magnetic rock intruding into sedimentary formations at shallow depths (shown as red colour). The lowest amplitude ranges from 0.02 to 0.009cycles (shown in yellow to green colour). These are regions with magnetic rock intruding into sedimentary formations at greater depths. The likely areas with high concentrations of mineral deposits (intrusive areas) correlate with high analytical signal amplitude. Analytical signal is shown in fig. 3a.

Horizontal Derivative: The enhancement provides a more comprehensive view of the linear patterns than vertical derivative map. The contacts between the sediments of the lower Benue Trough and the crystalline basement rocks have been delineated. Contact between crystalline basement materials at the central area of the study area and the Asu River group sandstone/shale is also designated using this enhancement. It is used to define boundaries of lateral variation in magnetization (see fig. 2c).



2A-Total magnetic Intensity map (overlain by shear zones (White bars); 2b-Vertical Derivative (VDA-Vertical shallow magnetic Anomalies/structures) derivative of the anomaly used to identify the shallow magnetic structures) *the solid lines used to demarcate the sedimentary boundaries and the basement on the study area are overlain on the maps).*

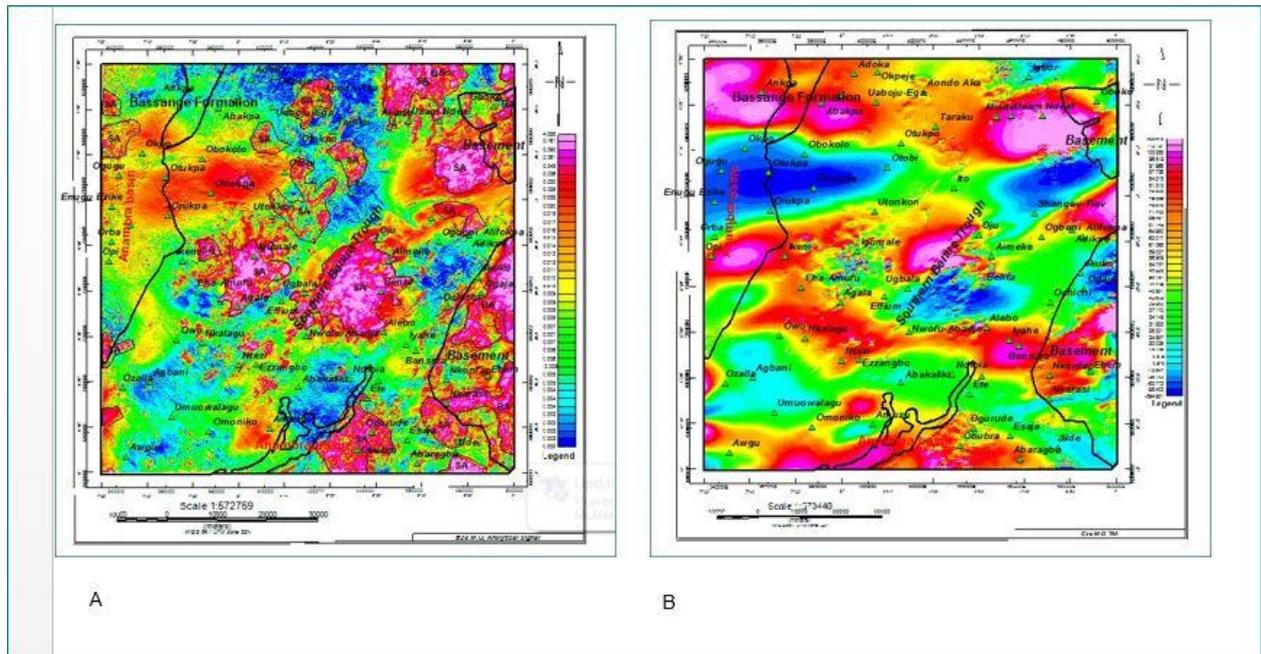
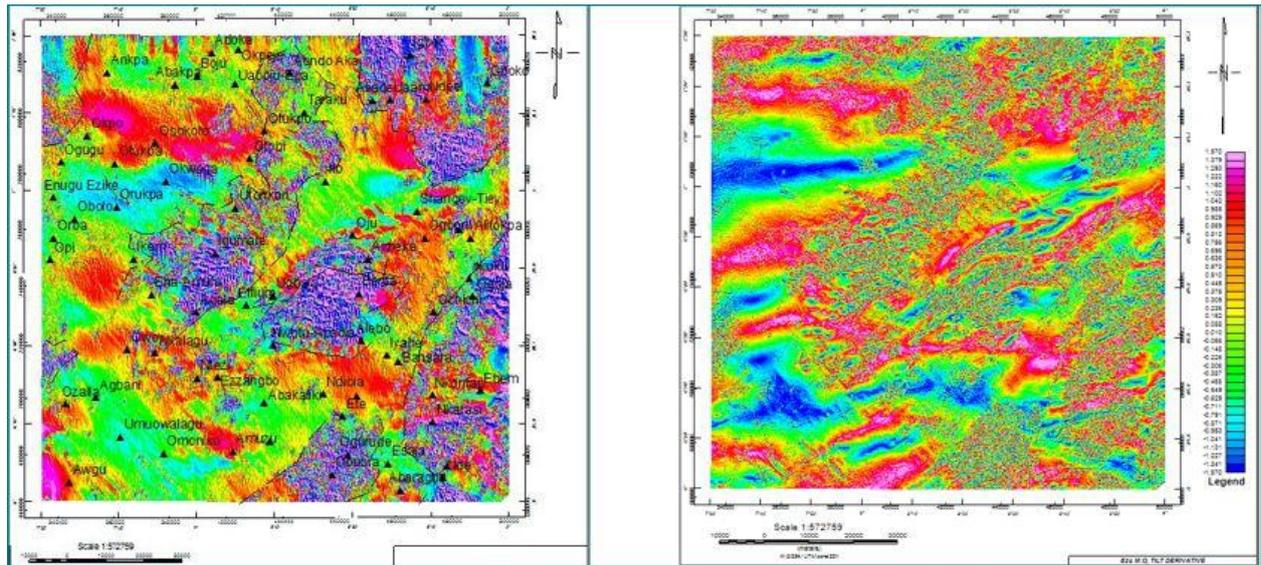


Figure 3a- Analytical signal (SA-Maximum analytical signal amplitude on the sedimentary basin; BA-Maximum analytical signal amplitude on the basement). Figure 3b- Total Magnetic intensity (TMI). *The solid lines used to demarcate the sedimentary boundaries and the basement on the study area are overlain on the maps).*



3C- Horizontal derivative of RTP of the TMI (dashed lines have been used to delineate boundaries of lateral variation in magnetization); 3D- Tilt derivative map.

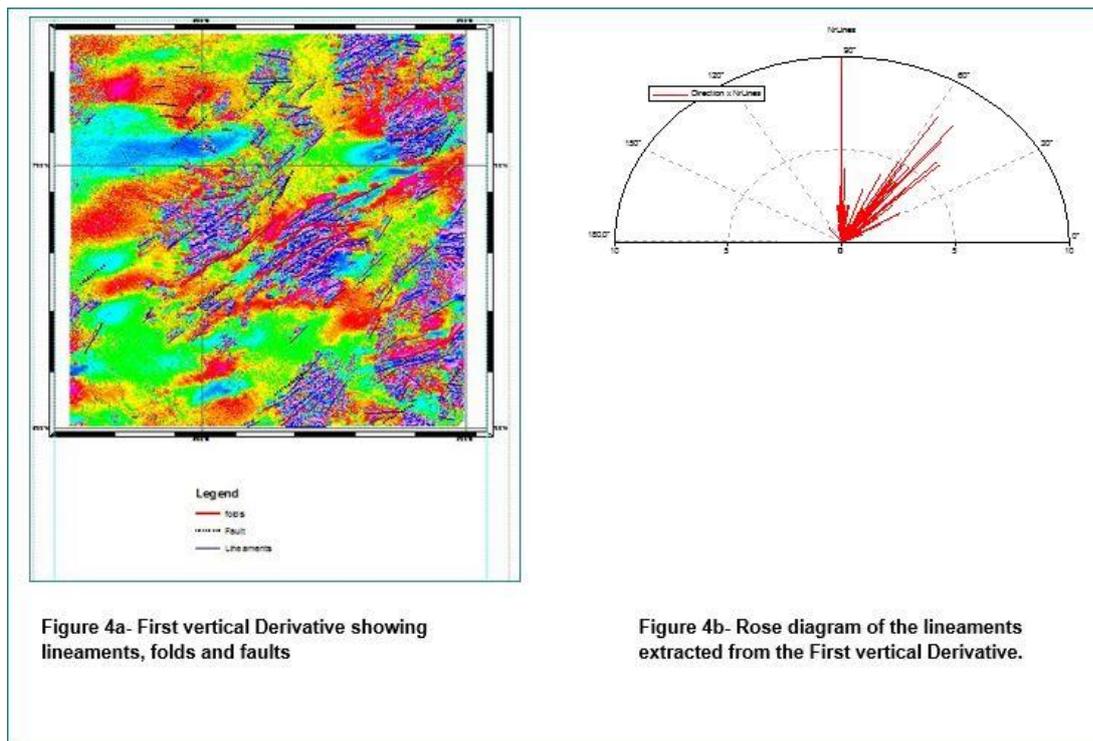


Figure 4a- First vertical Derivative showing lineaments, folds and faults

Figure 4b- Rose diagram of the lineaments extracted from the First vertical Derivative.

Aeroradiometric data

Ternary Map Image: Airborne gamma ray maps reflect the geochemical variations of K, U, and Th in the upper 30cm of the earth’s surface. Radiometric classification of Formation data and outcrop data into lithological categories was accomplished using Ternary map technique (Galbraith & Saunders, 1983). The false bedded sandstone of Ajali Formation has low content of radioactive element. The area covered by this lithology has dark colouration and this is an indication of decrease in radioactive content because black means low in Potassium, Thorium and Uranium in Ternary

map. The ternary map distinguished Nsukka Formation (occurring as outliers) from the Ajali Foramation at the Northern western part of the study area. The basements rocks at the Southeastern end that was grouped as undifferentiated granite were differentiated with ternary map (see fig. 1b & 5a). The white colouration portions are areas with high potassium, Thorium and Uranium. Part of Asu River Group, sandstone of Eze-Aku formation, Awgu-Ndeaboh formation and intrusive zones are standing out clearly and shows indication that the K, eTh and eU values are high. There is a dramatic increase in the potassium concentrations westwards into the Benue trough compared to the depletions of potassium in the Anambra basin. Potassium radiation essentially comes from K feldspar, predominantly microcline and orthoclase or micas such as muscovite and biotite which are common in felsic igneous rocks (e.g granite) and are low in mafic rocks (e.g basalts and andesite) but virtually absent from dunite and peridotites. The Asu River Group which is dominantly dark grey shale with sandstone intercalations, The Agbani Sandstone, the basaltic intrusions, the Granite Gneiss, the Eze-Aku Sandstone and Porphyritic granite/coarse porphyritic biotite hornblende granite on the northeast portion are showing dark red colouration on the ternary map as a result of high K- value content. The blackshale, siltstone and sandstone of Eze-Aku Formation have high Thorium value. The Awgu -Ndeaboh shale and limestone have more of uranium content with intermediate potassium value. The Porphyritic granite/coarse porphyritic biotite hornblende granite on the extreme south east portion of the area has more of Thorium value. The shale and Mudstone of Nkporo Formation have low potassium and high uranium content.

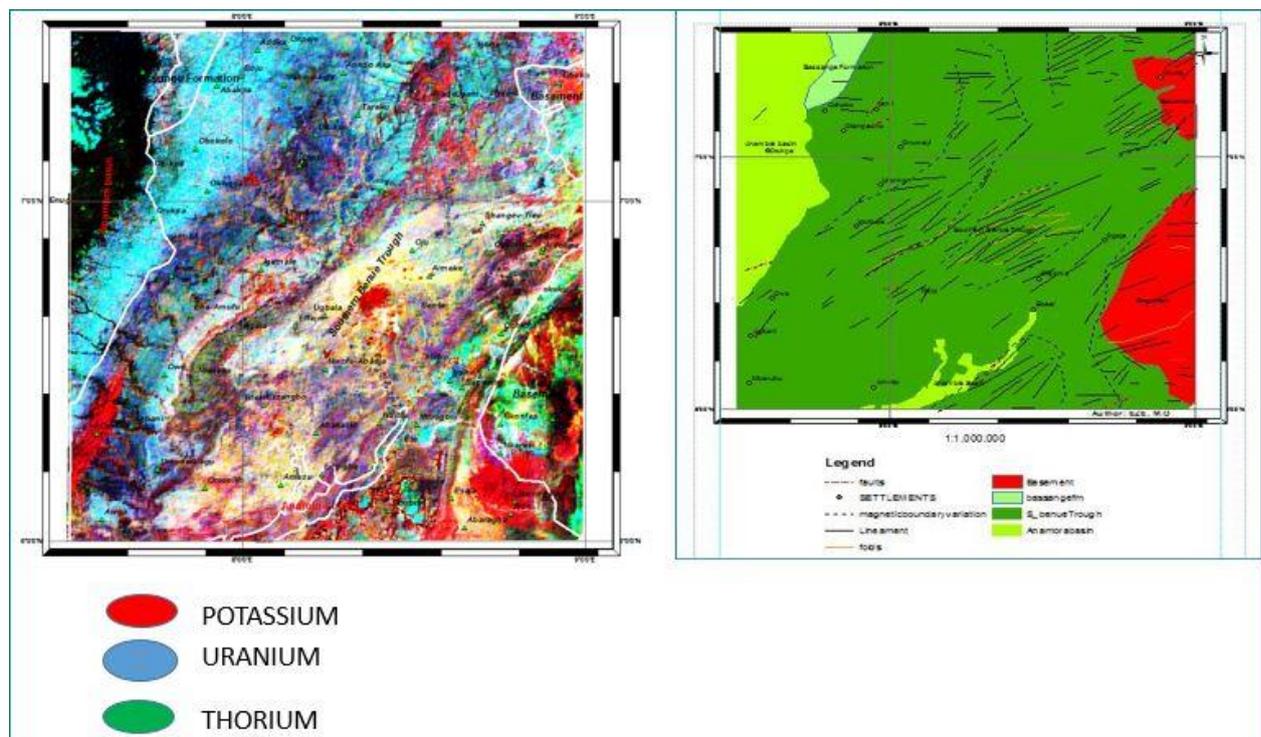


Figure 5A: TERNARY IMAGE. (The solid lines used to demarcate the sedimentary boundaries and the basement on the study area are overlain on the maps). **5B: Geology/structures from the magnetic data**

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REFERENCE

- Agugu, O.K., Fayose, E.A. and Peters, S.W., (1985):** Stratigraphy and sedimentation in the Santonian Anambra Basin of eastern Nigeria. *J. Mi. and Geol.*, v.22, p.25 - 36
- Amajor, L.C., (1985).** The Cenomanian hiatus in the southern Benue Trough, Nigeria, *Geol. Mag.*, v. 122, p. 39-50.
- ArcMap™ 10.3, ESRI Inc., New York Street Redlands, California U.S.A.
- Erwin Ebner, John Peirce and Nathalie Marchand (1995):** Interpretation of Aeromagnetic Data. CSEG Recorder September 1995.
- Galbraith and Saunders (1983):** Rock classification by characteristics of areal gamma-ray measurements. *J of Geochem. Explor.*, 18. 49-73.
- Keating, P.B. (1995):** A simple Technique to identify Magnetic Anomalies Due to Kimberlite Pipes. *Exploration and Mining Geology*, 4, 121-135.
- Kogbe, C.A (1975):** Geology of Nigeria Rock view Nigeria (limited). 536p.
- Macleod, et.al (1993):** 3-D analytical signal in the interpretation of total magnetic field data at low magnetic latitudes: *Exploration Geophysics*, 24, 679-688.
- Macleod, I. N., Jones, K., and Dai, T. F., (1993):** 3-D analytical signal in the interpretation of total magnetic field data at low magnetic latitudes: *Exploration Geophysics*, 24, 679-688.
- Milton, Dobrin and Carl Savit (1988):** Introduction to Geophysical Prospecting. McGraw-Hill Book Company 867p.
- Murat, R.C. (1972):** Stratigraphy and Palaeogeography of Cretaceous and Lower Tertiary in South Nigeria.
- Nabighian, M.N. (1984):** Towards a three-dimensional interpretation of potential field data via generalised Hilbert transforms: fundamental relations. *Geophysics*, 49, 780-786.
- Nabighian, M.N. (1972):** The analytic signal of two dimensional magnetic bodies with polygonal cross-section: its properties and use for automated anomaly interpretation. *Geophysics*, v. 37, 507-517.
- Nabighian, M.N. (1974):** Additional comments on the analytical signal of two dimensional magnetic bodies with polygonal cross-section. *Geophysics*, 39, 85-92.
- Nwachukwu, S.O. (1972a):** The tectonic evolution of the southern portion of the Benue Trough, Nigeria. *Geol. Mag.*, 109: 1775 – 1782.
- Nwajide, (2013):** Geology of Nigeria sedimentary basins. CSS press 565pp.
- Oasis Montaj, Version 6.4, Geosoft Inc. Queens Quay Terminal Toronto Canada
- Peters, S.W., Okereke, C.S., and Nwajide, C.S., (1987):** Geology of the Mamfe Rifts, Southeastern Nigeria.
- Reid, A.B., Allsop, J.M., Granser, H., Millet, A.J. & Somerton, I.W., (1990):** Magnetic interpretations in three dimensions using Euler deconvolution *Geophysics*, v. 55, pp 80-91.
- Reyment, R.A., (1965):** Aspects of Geology of Nigeria, Ibandan University Press, Ibandan University Press, , Nigeria, p.133.
- Roest, W.R., Verhoej, J., Pilkington, (1992):** Magnetic interpretation using 3D analytical
-

signal Geophysics, 57(1): 116-125.

Telford, et.al (1990): Applied Geophysics 2ndedn. Cambridge University press Cambridge.

Telford, W.M., Geldart, L.P. & Sheriff, R.E. (1990): Applied Geophysics 2ndedn. Cambridge University press Cambridge.

Uzuakpunwa, (1980): Petrography differentiation of tectonically controlled Cretaceous sedimentary cycles southeastern Nigeria. Sedimentary Geology, 17, 234 – 245.

Verduzco, B., Fairhead, J. D. and Green, C.M., (2004) :New insights into magnetic derivatives: The Leading Edge, 22, 116–119, doi:10.1190/1.1651454.

Wilford, et.al (1997): Application of airborne gamma ray spectrometry in soil/regolith mapping and applied geomorphology. AGSO Journal of Australian Geology and Geophysics. V. 17(2) 201-216.